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Minimally invasive transforaminal lumbar interbody fusion (MI-TLIF): A review of indications, technique, results and complications

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A B S T R A C T

Minimal access surgery has revolutionized most surgical disciplines and spine surgery is no exception. Minimally invasive transforaminal lumbar interbody fusion (MI-TLIF) was devised to reduce the approach-related morbidity of open TLIF and has flourished in the last decade. With expanding indications, standardization of technique and equipment, publication of more studies on its results and complications being brought to light – an update of the existing knowledge on MI-TLIF is imminent. We provide a review of the indications, technique, results and complications of MI-TLIF while also highlighting its variations and utility in special situations.

1. Introduction

Degenerative lumbar spine disease is one of the most rampantly prevalent healthcare problems in the world, with chronic low back pain being the second leading cause of adult disability in the United States.[1] The symptoms can broadly be divided into low back pain and radicular symptoms in the lower extremities leading in some cases, to neurogenic claudication. Whereas radicular symptoms may be relieved by decompression, discectomy or laminectomy at the appropriate location – these techniques have limited potential in relieving low back pain. Low back pain in such patients usually has a structural origin – from the degenerated disc, facet joints, spinal instability or sagittal malalignment – and necessitates spinal fusion of the indicted segment.

Lumbar spine fusion procedures have come a long way since the first description of the same by Albee[2] and Hibbs[3] in independent reports in 1911. The evolution of these spinal fusion procedures has seen some remarkable developments in the last century which include: description of ALIF (Anterior Lumbar Inter-body Fusion) by Burns(1933),[4] PLIF (Posterior Lumbar Inter-Body Fusion) by Cloward(1943),[5] pedicle screws by Roy-Camille(1970)[6] and TLIF (Trans-foraminal Lumbar Inter-body Fusion) by Harms and Rolinger(1982).[7] Along with development of carbon fibre cages and orthobiologics in the 1990s, each of these developments has contributed in achieving better fusion rates and clinical outcomes for lumbar spine fusion procedures. TLIF currently enjoys the pride of place in the armamentarium of spine surgeons dealing with lumbar degenerative disease. The more lateral exposure to the interspace in TLIF as compared to PLIF gives it three distinct advantages over the latter – i) minimal neural retraction, ii) thorough interspace preparation through a unilateral approach owing to its lateral-to-medial trajectory and iii) avoidance of the midline scar in revision cases (like recurrent disc herniations).[8]

The evolution of MAST (Minimal Access Spine Technique) in the last two decades has been nothing less than spectacular. Taking cue from the dramatic success of laparoscopic and endoscopic techniques in other surgical disciplines, spine surgeons have also focussed on 'minimalist' techniques. While excellent results were obtained with open TLIF, there was significant morbidity seen due to iatrogenic soft tissue and muscle injury that occurs with subperiosteal paraspinal muscle stripping and prolonged retractor application.[9–12] The unique set of symptoms attributed to the deleterious effects of surgical exposure in posterior spinal fusion procedures came to be known as the 'fusion disease'[8] – and manifested as post-operative back pain, delayed recovery and ambulation, decreased trunk muscle strength and poorer long-term outcomes. With an aim of achieving similar if not better outcomes with a smaller 'surgical footprint', MI-TLIF was described by Foley.[13] By employing smaller incisions and accessing the spine through paraspinal muscle-splitting surgical corridors, MI-TLIF causes significantly less soft-tissue and muscle disruption. Technological advances, better magnification and illumination, modern tubular

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retractors and percutaneous screw systems and more frequent exposure of surgeons to minimally access surgery in their residency training has greatly contributed to the global success of MI-TLIF. This review seeks to take the reader through the various nuances of MI-TLIF – its indications, operative technique, comparative results with open TLIF, technical challenges, complications and its utility in certain special situations.

2. Indications

The goals of all lumbar fusion surgeries – whether open or minimally-invasive - remain the same: i) Adequate neural decompression, ii) Restoring spinal alignment and iii) Preventing abnormal motion with fusion. Broadly, the indications for minimally invasive TLIF are the same as that of open TLIF – however, in special conditions, one of these techniques might be preferred over the other. Needless to say, a surgeon must be proficient in both open TLIF and in more straightforward minimally invasive procedures like microdiscectomy before performing regular MI-TLIF surgeries.

Table 1 details the indications of MI-TLIF[14,15]:

Table 1
Indications of MI-TLIF

Indications where MI-TLIF and open TLIF are equally preferable
Severe degenerative disc disease (DDD)
Low-grade spondylolisthesis (Grade 1 and 2)
Post-laminectomy instability
Pseudarthrosis
Trauma requiring interbody fusion
Indications where MI-TLIF is preferred over open TLIF
Recurrent disc herniation
Obese patient[16]
Indications where open TLIF is preferred over MI-TLIF
Multiple level surgery (spondylolisthesis, DDD, lumbar canal stenosis)
High-grade spondylolisthesis (Grade 3 and 4)
Distorted anatomy

The benefits accrued by MI-TLIF over open TLIF in recurrent disc herniations are largely as a result of avoiding the post-operative scar tissue in the midline. In obese patients, open technique requires a larger exposure for adequate retraction to visualize the pedicle screw insertion landmarks making percutaneous screw insertion more appealing. The usual association of comorbidities like diabetes mellitus in this group of patients also places them at a greater risk of post-operative infection, which makes a minimally-invasive technique preferable. Most surgeons prefer open TLIF for high-grade spondylolisthesis. Multiple-level surgery is also more often treated by open TLIF to evade longer operative times and increased radiation exposures associated with the former.

3. Operative Technique[17]

1) **Positioning:** Patients are positioned prone on a radiolucent table after induction with general anaesthesia. Prior to painting and draping, we ensure that the abdomen is hanging free to avoid engorgement of epidural venous plexuses. Some surgeons also perform 'Awake' MI-TLIF under conscious sedation or spinal anaesthesia.[18,19] Optimal sagittal balance or lumbar lordosis on the operating table is obtained by either using a standard table with bolsters or an open Jackson frame table (Fig. 1). The patient is then prepared and draped.
2) **Incision and localization:** The first and practically the most essential step at this stage is appropriate C-arm positioning. The C-arm should be positioned in such a manner that: i) the spinous process is precisely in midline, ii) the superior and inferior end plates of the vertebra to be instrumented are parallel in both AP and lateral views, iii) there is no rotation in the vertebra (Fig. 2). Small 2–3 cm paramedian skin incisions are given under C-arm guidance, just lateral to the lateral border of the pedicles – typically ~5 cm from the midline. The incision is carried further down through the subcutaneous tissue and the underlying fascia. Using blunt dissection with a finger, the planes are split further to create a 'surgical corridor' for percutaneous screw insertion.
3) **Percutaneous pedicle screw and rod placement:** Jamshidi needles (#11) are inserted through these 'corridors' and parked at the junction of the transverse process and superior facet. Fine adjustments of the needle position are made under AP fluoroscopy guidance. The pedicle entry site will be at the 10'o clock position of the pedicle for left sided pedicles and at 2'o clock position for right sided pedicles. Each needle is then advanced roughly 2 cm, taking care not to pass beyond the medial border of the pedicle projection on AP fluoroscopy (Fig. 3A). Upon insertion to such a depth, the needle tip should lie in the posterior third of the vertebral body on lateral fluoroscopy (Fig. 3B).

Fig. 1. Patient positioned on an open Jackson frame table.

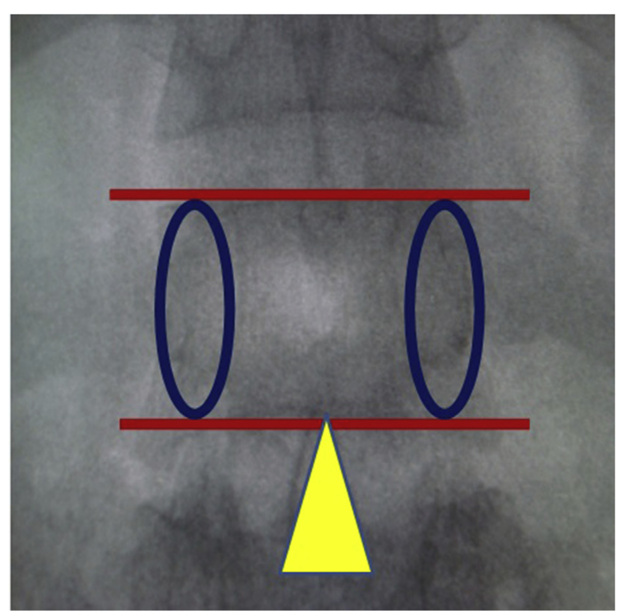

Fig. 2. The ideal AP fluoroscopy view before starting percutaneous screw insertion. Note that both endplates are parallel, spinous process is in the centre and both pedicles are symmetrical ovals (no rotation).

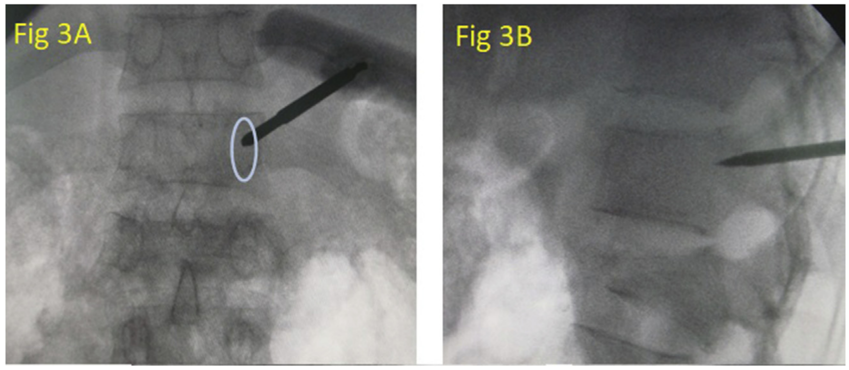

Fig. 3. Showing Jamshidi needle insertion under fluoroscopy guidance. Note that when the needle reaches the medial wall of the pedicle in AP view (Fig. 3A), the needle is in the posterior third of the vertebral body in lateral view (Fig. 3B).

A high incidence of cranial facet violation following percutaneous pedicle screw insertion has been reported[20] and it would be prudent to start more lateral and inferior on the pedicle to ensure that the screw head does not impinge on the cranial facet joint – something that could potentially lead to future adjacent segment degeneration (ASD). Following this, the trocar from the Jamshidi needle is taken out and a guide-wire is inserted through the needle. The Jamshidi needle is removed while holding the guide-wire in place. Sequential dilators follow the guide-wire and finally the percutaneous pedicle screw, loaded with long, radiolucent soft tissue retractors is inserted over the guide-wire with or without prior tapping (Fig. 4A, B, 4C, 4D). Next, a pre-contoured rod of appropriate size in inserted, typically on the side opposite to that of patient's radicular symptoms. Using a special insertion handle, the rod is inserted underneath the fascia from the end where the pedicle head is closer to the skin (usually the cranial end). Set screws (innies) are then placed through the sleeves to put the rod in place.

4) **Bony Decompression:** Before proceeding to resection of bone, temporary distraction is done over the contralateral rod. Next, a guide pin is inserted – most appropriately on the ipsilateral facet joint and tubular dilators are passed sequentially until a final expandable dilator is in place (Fig. 5). After coagulating the soft tissue and vasculature, the pars interarticularis is identified and exposed. The resection of bone essentially involves ipsilateral hemilaminectomy and near complete facetectomy (whole of inferior facet and upper part of superior facet). This is carried out by a combination of sharp osteotomes and Kerrison rongeurs/upcutters. Burrs are best avoided if one plans on using locally harvested bone as autograft. After developing an appropriate sublaminar plane with a probe/Penfield dissector, the ligamentum flavum is carefully excised to expose the underlying thecal sac. An almost pedicle-to-pedicle exposure is obtained at this stage – the disc space and the traversing nerve root will lie in the lower half of this space, whereas the exiting nerve root will lie in the upper half of this space. Dissection and exposure of the exiting nerve root is not mandatory unless one intends to reduce a Grade 3 or 4 anterolisthesis or the patient has relevant symptoms which can be attributed to exiting nerve root compression.
5) **Disc Space Preparation and Interbody Fusion:** Once the traversing nerve root is identified and adequately mobilized, it is

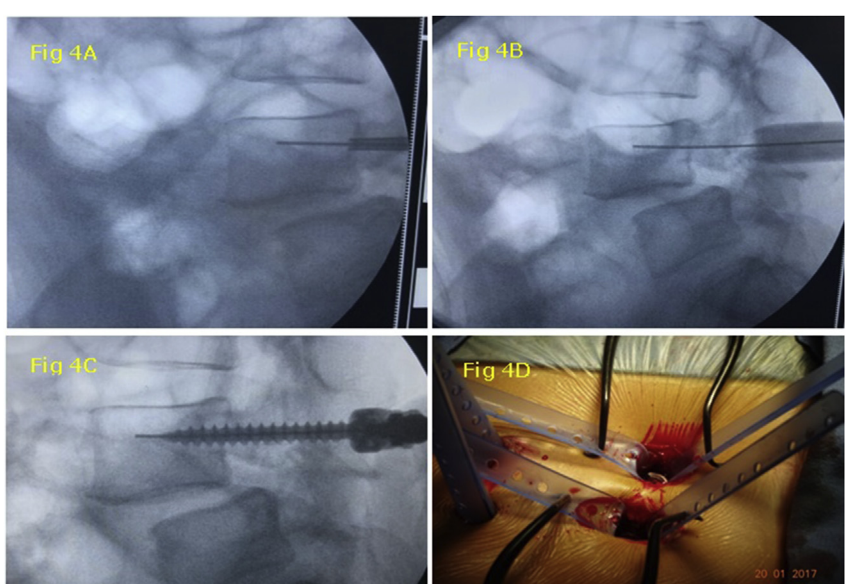

Fig. 4. Steps of pedicle screw insertion. 4A: Guide wire inserted through Jamshidi needle, 4B: Sequential dilators passed over guide wire, 4C: Pedicle screw inserted over guide wire, 4D: Exposure with retraction sleeves to aid rod placement.

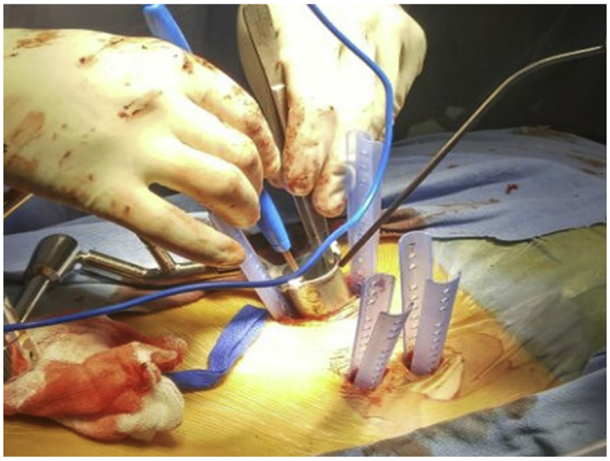

Fig. 5. Decompression and TLIF done through space created by a tubular dilator.

retracted medially using a probe or a dura protector. The annulus is incised using a long-handled scalpel and a thorough discectomy is performed using a combination of shavers, pituitary forceps and curretes. The instruments are angled lateral-to-medial to reach the contralateral part of the disc space as well. The cartilaginous end-plates must be denuded completely with curretes and rasps to provide a broad area of cancellous bone for solid bony fusion. A complete and meticulous disc space preparation, including removal of disc material and cartilaginous end plates, is the key to a successful interbody fusion and this step should be done patiently and industriously. Typically, 60–80% of the disc space can be effectively prepared for fusion via a MI-TLIF unilateral approach.[17] Using a funnel, the disc space is then partially packed with morcellized locally harvested bone graft meant to lodge in the anterior disc space. A cage (Polyetheretherketone – PEEK/titanium) of an appropriate size is then chosen. While some surgeons prefer to use trial implants to estimate the size of the cage to be used, a sound estimate can also be made from the 'tight feel' of the largest shaver inserted previously. The cage is packed with bone graft and after insertion, is positioned in the disc space using a combination of impactors so that it lies in the centre-anterior portion of the disc space and rests on the stronger anterior ring apophysis rather than just the soft central cancellous portion, to prevent delayed cage subsidence.[17] Some surgeons prefer sealing the annulotomy with a fibrin sealant such as Tisseel (Baxter Biosurgery, Deerfield, IL) and a gelfoam to prevent subsequent leakage from the disc space which can potentially cause chemical radiculitis or seroma formation. Our use of such materials is restricted to cases where there is an inadvertent dural tear. A pre-contoured rod is inserted on the opposite side to complete the surgical procedure. The previously applied temporary distraction is released so that the cage gets impacted well on both superior and inferior vertebral surfaces. Further compression is done over the rod bilaterally. Usually, the combination of facet release, cage insertion, foraminal height restoration and initial rod distraction and later rod compression helps in achieving the twin goals of reducing a low-grade spondylolisthesis and restoring the local sagittal balance. For reduction of high-grade spondylolisthesis, one might be required to use threaded reduction screws.

6) **Wound closure:** After thorough wash and achievement of hemostasis, remaining bone graft is packed in the posterolateral gutters. Fascia is closed with continuous absorbable sutures, subcutaneous tissue with absorbable interrupted sutures and skin with conventional staples or a surgical closure system like Zip® Surgical Skin Closure (Zipline Medical, CA).

4. Search methodology

Our search methodology involved a Medline search with the Medical subject Heading(MeSH) term 'Intervertebral Disc Degeneration' and the subheadings 'surgery' and 'therapy'. Search keywords included a combination of 'minimally invasive', 'MI-TLIF', 'TLIF', 'transforaminal lumbar interbody fusion' or 'minimally invasive spine surgery'. We set the following criteria for a study to be included in our review: i) Published after 2009, ii) full text available, iii) Pubished in English language, iv) comparative study design (MI-TLIF v/s open TLIF, v) at least 10 patients in both groups (MI-TLIF v/s open TLIF), vi) at least 24 months follow-up, vii) patients suffering single-level degenerative disc disease or isthmic spondylolisthesis, viii) atleast two or more clinical outcomes reported. Both the authors independently screened the titles, abstracts and full texts to ensure fulfilment of the inclusion criteria – any difference in opinion was settled by discussion until a consensus was reached. The arbitrary limit of last 10 years set for the inclusion of studies was done to ensure a uniformity in instrumentation, technique and other operative parameters across studies and also to include only those studies where the operative setting will most closely resemble the present scenario. However, we recognize that this represents a potential bias and hence, remains a limitation of our search methodology.

5. Discussion

5.1. Comparative studies with open TLIF

Several studies have been published, more so in the last decade, comparing open TLIF and MI-TLIF. Even though MI-TLIF is established worldwide as a surgical procedure, there is a lack of adequately powered, clinically robust, multi-centre randomized controlled trials which directly compare open TLIF with MI-TLIF. Existing systematic reviews and meta-analysis suffer from limitations – reliance on retrospective and prospective cohorts, publication bias for a newer technique, lack of standardization of MI-TLIF procedure at different centres, differing surgical experience and skills of various surgeons and lack of standardized reporting or outcome scores. Using our search methodology, we narrowed down to 11 studies which fulfilled our inclusion criteria. Thus, the current evidence is based on various prospective and retrospective studies – the findings of which are summarized in Table 2.

To summarize, existing studies differ greatly in terms of study design, measured outcome variables and most importantly, the precise surgical technique used for performing MI-TLIF. However, most studies agree that MI-TLIF leads to lesser intra-operative blood loss and shorter hospital stay compared to open TLIF. Some studies report longer operating times with MI-TLIF whereas the other report no significant difference – the disparity can be due to the differing experience of the operating surgeons/team with the minimally invasive technique. Clinical patient-reported outcome scores do not differ between the two groups in long-term follow-up with MI-TLIF faring slightly better in short-term follow-up.

5.2. Variations of MI-TLIF and their outcomes

Some authors have reported technical modifications in the MI-TLIF procedure. Mummaneni[31] described a mini-open TLIF procedure where an expandable tube retractor was placed using a

Table 2
Comparison of minimally invasive and open TLIF.

Study	Year	Design	Patients (MI:Open)	Follow-up (MI/Open)	Comments/Significant findings
Schizas et al.[21]	2009	PC	18:18	22.0/24.0	MI-TLIF: lesser EBL, shorter LOS (statistically significant difference), Steeper learning curve ODI, VAS scores – difference statistically insignificant
Peng et al.[22]	2009	PC	29:29	24.0/24.0	MI-TLIF: higher fluoroscopy and operating time, lesser EBL, shorter LOS (all statistically significant) ODI, VAS scores, fusion rates – difference statistically insignificant
Villavicencio et al.[23]	2010	RC	76:63	37.5/37.5	MI-TLIF: lesser EBL, shorter LOS (both statistically significant) Higher rates of neurological deficit with MI-TLIF
Wang et al.[24]	2010	PC	42:43	26/26	MI-TLIF: lesser EBL, shorter LOS, lower post-operative VAS at 3rd day after surgery (all statistically significant) More radiation exposure with MI-TLIF VAS and ODI at final follow-up same between both groups
Lee et al.[25]	2012	PC	72:72	24.0/24.0	MI-TLIF: 3 times more fluoroscopy time, 88% decrease in EBL, shorter LOS (all statistically significant) ODI, VAS scores, fusion rates – difference statistically insignificant
Rodriguez-Vela et al.[26]	2013	PC	21:20	45.0/45.0	Clinical outcome scores (ODI, VAS, NASS score, SF-36) – all better with MI-TLIF but difference not statistically significant
Brodano et al.[27]	2013	RC	30:34	23.0/25.0	MI-TLIF: shorter LOS, lesser EBL, higher operating time (all statistically significant) Better early post-operative pain scores (VAS score on day 3 after surgery) with MI-TLIF, Better ODI at 1 month after surgery with MI-TLIF – both statistically significant No difference in VAS, ODI at final follow-up
Parker et al.[28]	2013	PC	50:50	24.0/24.0	MI-TLIF: shorter LOS, lesser EBL, higher operating time (all statistically significant) Similar outcome scores (ODI, VAS) and complication rate MI-TLIF more cost-effective than open TLIF
Saetia et al.[29]	2013	RC	12:12	28.0/28.0	MI-TLIF: lesser EBL No statistically significant difference in clinical outcome scores, (VAS, ODI) at 2 years, fusion rates, LOS, operating time, complication rate
Sulaiman et al.[30]	2014	RC	57:11	24.0/24.0	MI-TLIF: lesser EBL, longer operating time (both statistically significant) No difference in clinical outcomes (ODI, VAS) or LOS MI-TLIF more cost effective in terms of direct hospital cost
Wong et al.[17]	2014	PC	144:54	45.0/46.0	MI-TLIF: shorter LOS, lesser EBL, shorter operating time (all statistically significant) Better ODI at 4 years with MI-TLIF Similar fusion rates Higher radiation exposure with MI-TLIF (statistically significant)

[PC = Prospective cohort, RC = Retrospective cohort, EBL = estimated blood loss, LOS = length of (hospital) stay, ODI = Oswestry disability index, VAS = visual analog scale, NASS = North American Spine Society, SF-36 = Short Form 36 Health Survey].

muscle-splitting Wiltse approach. Screws were inserted and decompression with interbody fusion was done through the space afforded by this expandable retractor. The author proposed that the learning curve for this procedure was less than that for MI-TLIF. Dhall[32] compared their results of mini-open TLIF and open TLIF and reported that while the mean blood loss and length of hospital stay was lower with mini-open TLIF without affecting the outcomes, the incidence of hardware-associated complications was also higher with the mini-open TLIF.

In an attempt to further reduce approach-related morbidity, unilateral pedicle screw fixation with MI-TLIF has been proposed. Deutsch et al.[33] reported on a prospective cohort of 20 patients who underwent MI-TLIF with unilateral pedicle screw fixation. There was significant improvement in mean ODI and VAS scores, and 13/20 patients showed evidence of fusion in CT scans done at 6 months. However, a more recent study by Choi et al.[34] with a longer follow-up (mean = 28.2 months, minimum 2 years) showed that while the operating time and blood loss were significantly less with unilateral screw fixation with similar clinical outcomes, the fusion rates at 2 years were less than that with bilateral screw fixation (unilateral 82.6%, bilateral 95.7%). In a pilot study, Jang and Lee[35] used ipsilateral pedicle screw and contralateral facet screw fixation via a MI-TLIF approach. At a mean follow-up of 19 months, they reported significant improvements in mean numerical rating scale and ODI.

Reinshagen et al.[36] have recently described a novel minimally invasive technique for decompression and interbody fusion known as hybrid lumbar interbody fusion (HLIF). The technique combines the advantages of PLIF and TLIF. Using a standard posterior midline approach unilaterally, decompression and partial facetectomy are carried out, allowing for the implantation of a specially designed cage. Ipsilateral screws are inserted in a dorsoventral fashion, with a vertical vector using neuronavigation. Contralateral pedicle screws are inserted in a percutaneous fashion through small stab incisions under fluoroscopy guidance. Awake MI-TLIF has been performed by some surgeons to achieve a rapid and painless recovery and essentially make it a day-care surgery. Wang et al.[18] described their experience with this technique in which they utilized conscious sedation using an infusion of propofol and ketamine and injection of the percutaneous pedicle screw tracts with liposomal bupivacaine. Nine out of 10 patients in their cohort could be discharged on the 1st post-operative day.

5.3. Complications and technical challenges

In a recent meta-analysis, although MI-TLIF was reported to have a lower complication rate than open TLIF, the difference was not statistically significant.[37] Wang[38] in 2014 and Wong[39] in 2015 reported on two of the largest series of perioperative complications when doing MI-TLIF. In a retrospective cohort study on 204 patients who underwent MI-TLIF, Wang reported a complication incidence of 31.37%.[38] Only 7 were persistent complications, with the rest being transient. Of note, there were 24 patients with leg sensory disturbance after surgery. Ten small dural tears during decompression were managed with tight closure of the overlying fascia – no additional exposure and repair was done. Wong et al.[39]

performed a retrospective analysis of 513 patients which included both single-level and multi-level fusions using MI-TLIF. Of the 80 patients (15.4%) who had a perioperative complication – 53 had a surgical complication and 37 had a medical complication. Durotomy (5.1%) was the most common complication followed by instrumentation failure (2.1%). Performing a multi-level TLIF significantly increased the chances of complication as compared to single-level TLIF.

Some complications are unique to MI-TLIF though with a meticulous technique, they have been scarcely reported. Changing the direction of the screw over the guide-wire can lead to breakage of the guide-wire within the vertebral body or pedicle which can be difficult to retrieve. Percutaneous technique can be challenging at the L5/S1 level due to the pedicle angulations of L5 and S1.[40] The long retraction sleeves can impinge on each other at the skin level. To deal with this, one can either place the S1 pedicle screw in a more inferior starting position, or use flexible retraction sleeves which can be deflected at skin level.[40] Cannulation of small and sclerotic pedicles can be another potential problem. Sometimes, if one is not careful, guide wires can migrate anteriorly and can injure viscera or vascular structures.

Two important misgivings remain in most surgeons' minds regarding MI-TLIF: the steep learning curve and the increased amount of radiation exposure. Lee et al.[41] analyzed their results on the first 90 single level MI-TLIF performed by a single surgeon in a prospective cohort study and noted that technical proficiency for MI-TLIF was achieved after 44 surgeries and the patients operated after this achieved a better clinical outcome and had shorter LOS and operative time. Another study which plotted the operative times of MI-TLIF cases against experience noted that a 50% learning milestone was achieved at case 12 and a 90% learning milestone was achieved at case 39. MI-TLIF invariably places the surgeon to additional radiation exposure when compared to open TLIF. Bindal et al.[42] recorded the mean fluoroscopy time in 24 consecutive patients (33 MI-TLIFs). The mean fluoroscopy time was 1.69 min/case, and mean radiation exposure to dominant unprotected hand, waist under lead, and unprotected thyroid were 76, 27, and 32 mrem/case, respectively. A surgeon would thus exceed OELs (occupational exposure limit), in 194 cases for torso, 664 for hand, and 166 cases for unprotected thyroid annually. Use of navigation for screw insertion, protective gear, collimation, 'spot' radiographs and pulsed fluoroscopy have been recommended as some of the measures to deal with this problem.[43]

6. Conclusion

- MI-TLIF is a versatile technique with its spectrum of indications rivaling that of its open counterpart.
- Meticulous operative technique is the key to a good outcome in MI-TLIF
- MI-TLIF offers several advantages over open TLIF while giving similar clinical and radiological outcomes. The advantages include lesser blood loss, shorter hospital stay, faster rehabilitation and decreased need for analgesia and blood transfusions. These advantages are offset by a steeper learning curve, longer operating time and increased radiation exposure with MI-TLIF.
- High-powered, well-designed randomized controlled trials are needed to further validate MI-TLIF.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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